

# RADIO ASTRONOMY EXPERIMENTS WITH PLANETARY PROBES

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(on behalf of the PRIDE team)

# *Space exploration & radio astronomy: 53 years together*

- Glorious start: Sputnik and 76-m Mk1 Jodrell Bank (now Lovell) telescope, 4 October 1957
- Parkes receives the first TV images of Appolo-11 on the Moon, 21 July 1969



Lovell 76 m, Jodrell Bank, UK



ADU-1000, Evpatoria, Ukraine



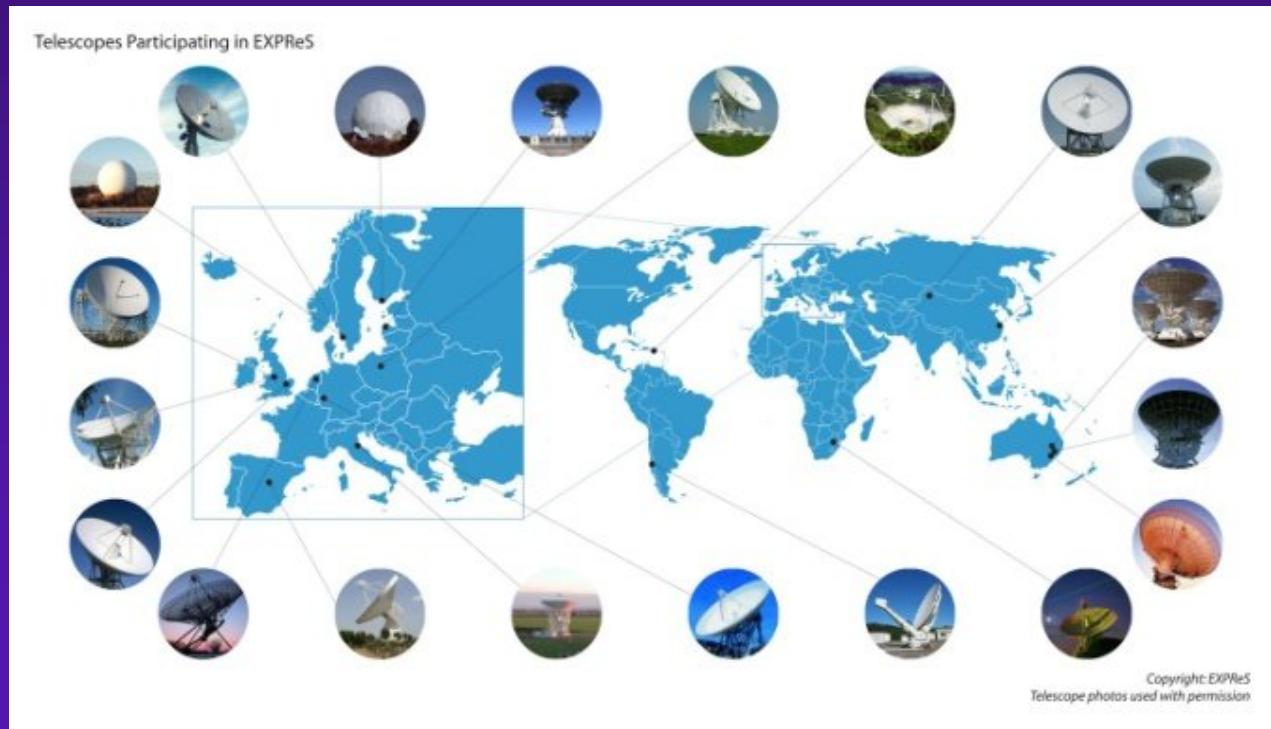
- Discovery of variability of extragalactic radio sources using deeps space communication antenna by G.B.Sholomitsky, 1965

Barcelona, Spain

13-17.06.2010

# PRIDE

PRIDE - Planetary Radio Interferometry and Doppler Experiments is the initiative carried out by the European VLBI Network consortium (EVN) to study a possible contribution and scientific return of the planned ESA planetary missions by enhancing the ground segment of the missions by a network of radio astronomical telescopes

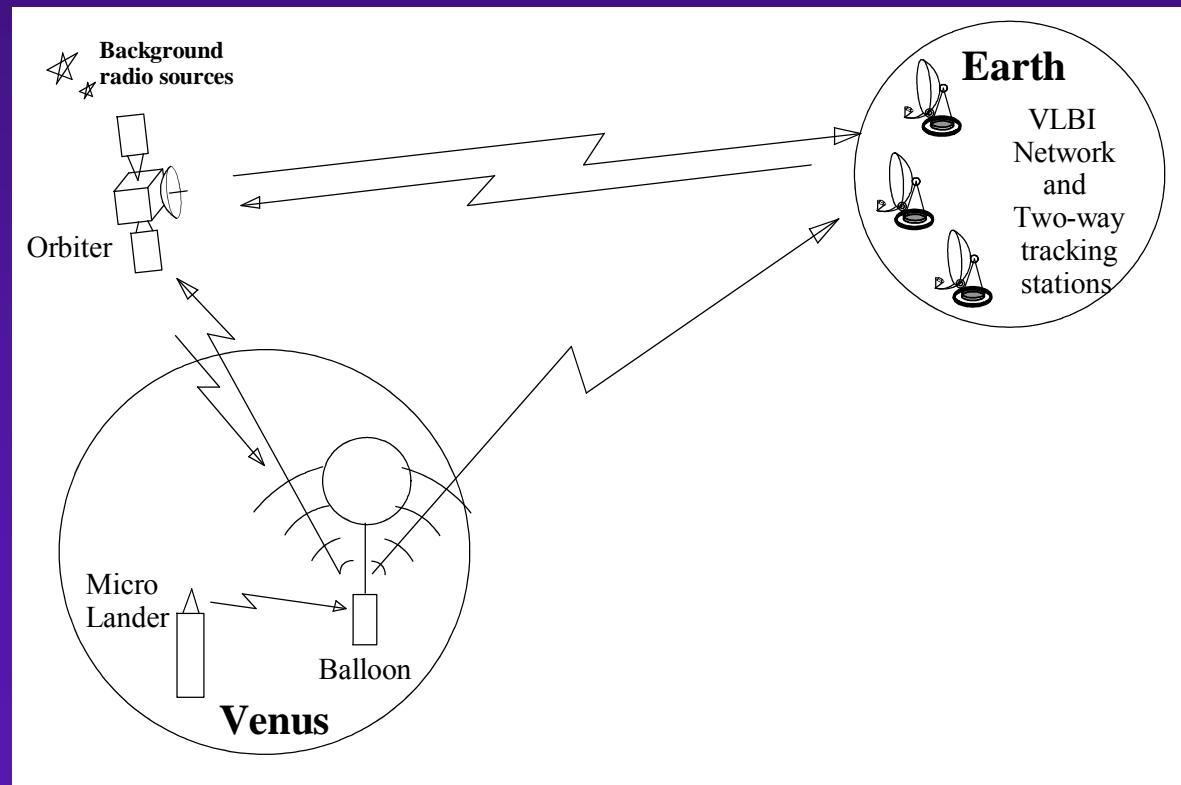


Current network of the EVN and associated radio telescopes, connected to the processing center at JIVE, Dwingeloo, The Netherlands

# Generic PRIDE configuration

Major components of the initiative scientific study and R&D activity:

1. VLBI tracking of the planetary probes
2. Doppler tracking in the One-Way or Multi-Way signal reception mode
3. Propagation media effects study
4. Direct-to Earth telemetry data reception from planetary probes, landers, penetrators, etc
5. Passive radio spectroscopy of the natural molecular lines from planetary environments



# 1. VLBI

# *VEGA balloons VLBI tracking, 1986*

$f = 1.6 \text{ GHz}$ ,  $\Delta f = 2 \text{ MHz}$ , 20 radio telescopes



$$\sigma_x = 10 \text{ km}$$
$$\sigma_v = 1 \text{ m/s}$$

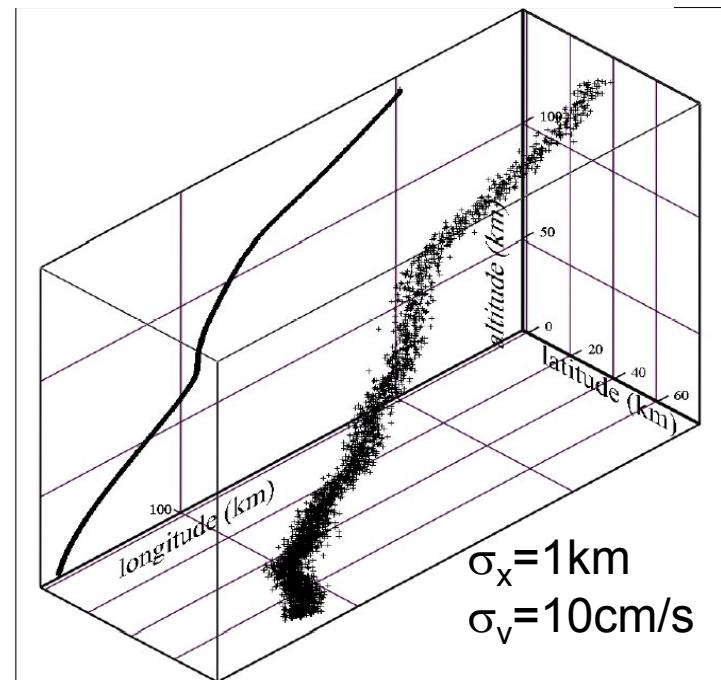
# *Huygens VLBI tracking: with 20 photons/dish/s*



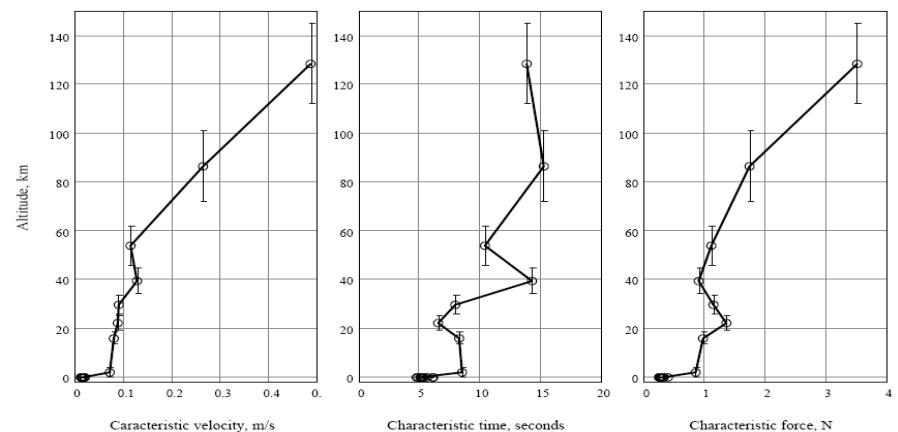
Titan, 14 January 2005

- Ad hoc use of the Huygens “uplink” carrier signal at 2040 MHz
- Utilised 17 Earth-based radio telescopes
- Non-optimal parameters of the experiment (not planned originally)
- Achieved 1 km accuracy of Probe’s descent trajectory determination
- Assisted in achieving one of main science goals of the mission – vertical wind profile

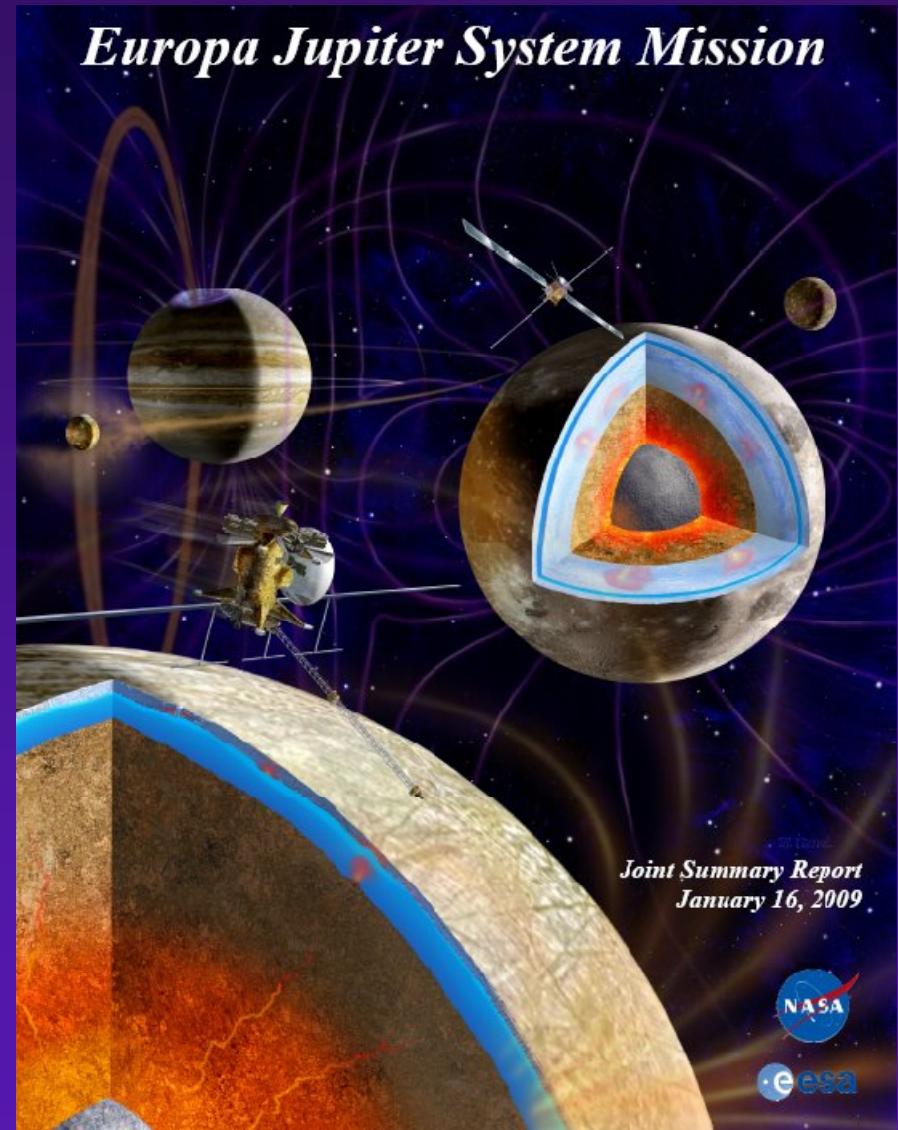
**3D Huygens descent trajectory**



**Titan atmosphere turbulence signature**



# *ESA Cosmic Vision and NASA Flagship proposals*



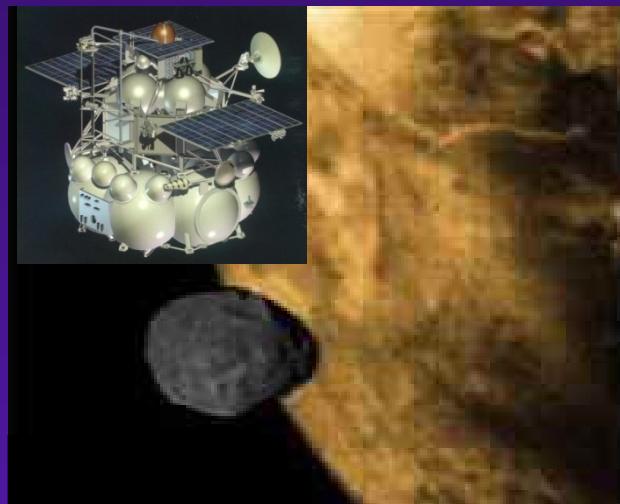
# PRIDE-EJSM vs Huygens VLBI tracking

Mission	Distance	Transmitter power/gain	Band	Time resolution	Delay noise	Positional accuracy (lateral)
	[AU]		[GHz]	[s]	[ps]	[m]
Huygens VLBI	8	3 W / 3 dBi	2.0 (S)	500	15	1000
PRIDE EJSM	5	10 W / 6 dBi	2.0 (S)	100	5	120
			8.4 (X)	10	3	70
			32 (Ka)	10	1	23

**GPS accuracy anywhere in Solar System**

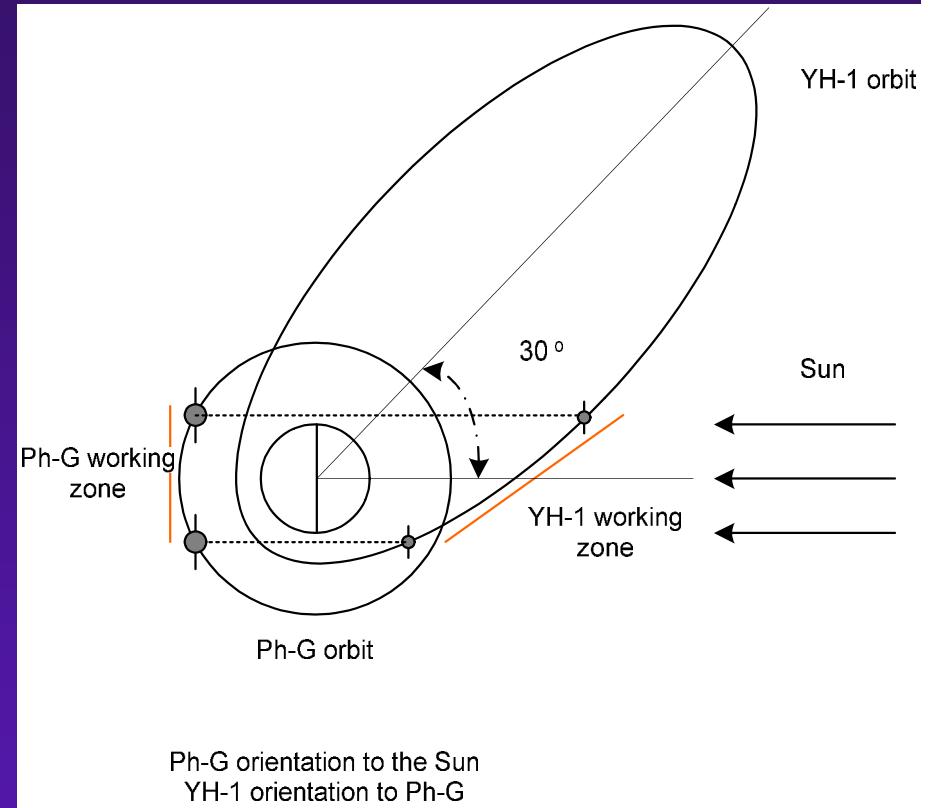
- Conservative estimate, today's technology
- Minimal special requirements for the on-board instrumentation
- In-beam “Orbiter-Probe” calibration can improve SNR further

# *Phobos-Grunt mission, VLBI observations of the lander are planned*



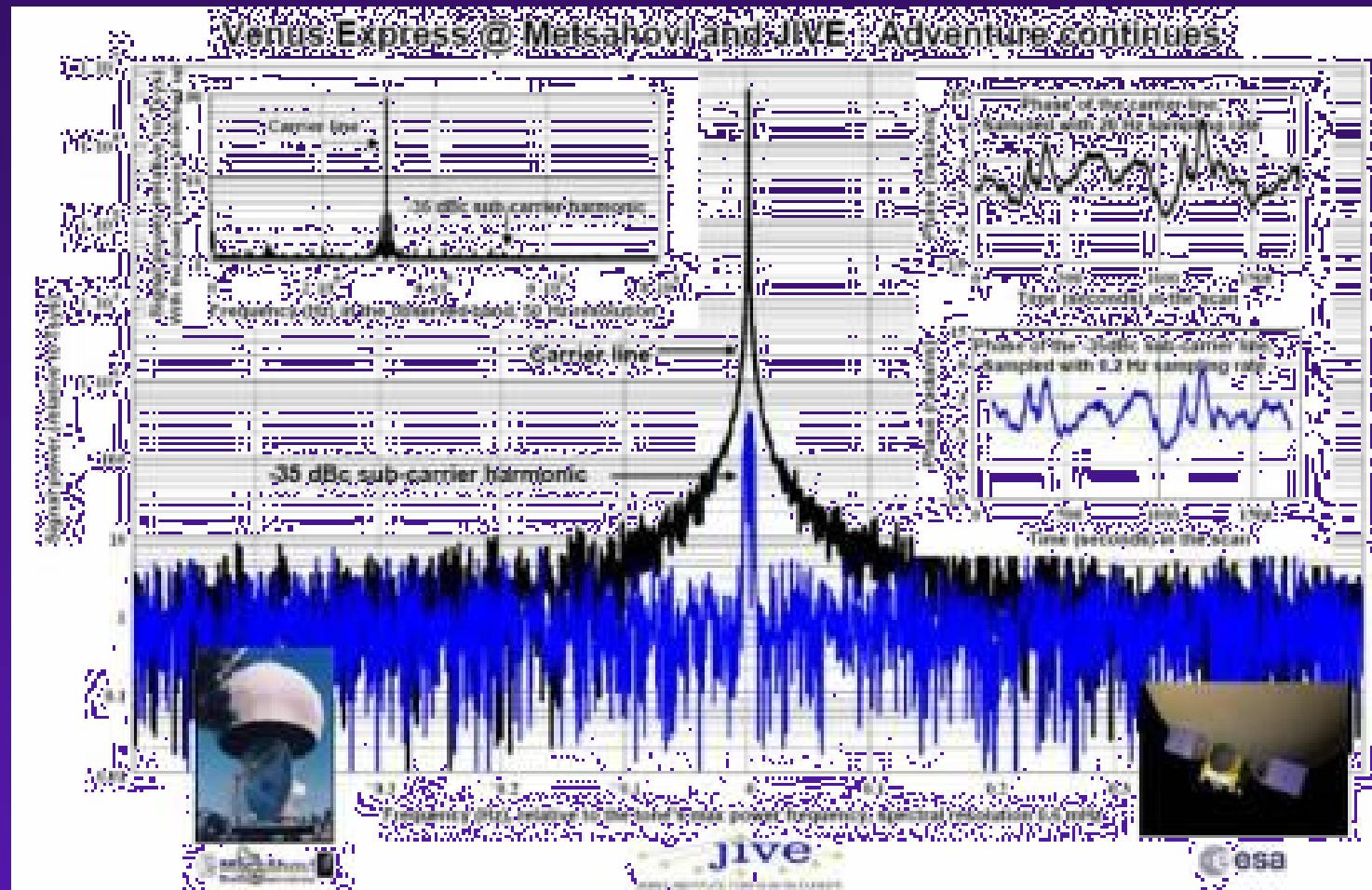
## Objectives:

- Ultra-precise estimates of the Phobos orbital parameters – variations, evolution, etc.;
- Input into estimates of fundamental parameters of Solar System;
- Mars and Phobos gravitational field studies – gravimetry, internal structure, etc.
- Synergy with the “Libration” experiment



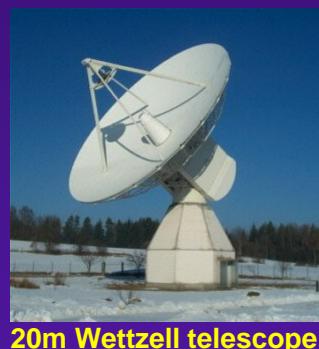
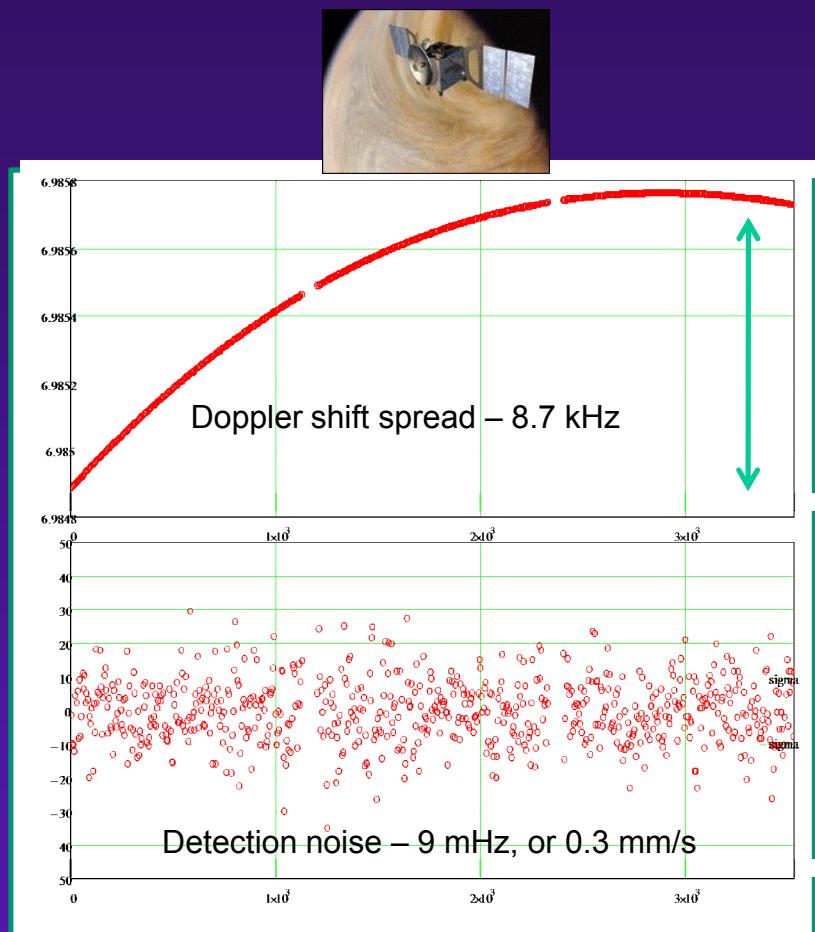
2. Doppler tracking in the One-Way or Multi-Way signal reception mode
3. Propagation effects study and Interplanetary plasma diagnostics

# VEX Doppler tracking demo, 2008, 14m Metsähovi telescope



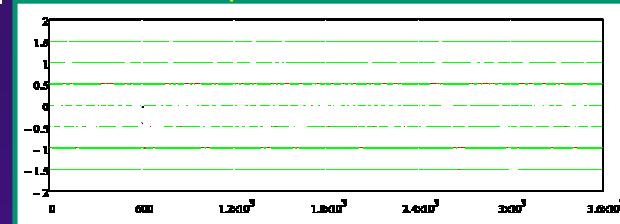
- ESA's Venus Express carrier spectrum,
- Metsähovi observation,
- New S/W spectrometer
- 0.6 mHz spectral resolution
- 70 dB dynamic range

# VEX Doppler tracking demo, 2010, 20m Wettzell telescope

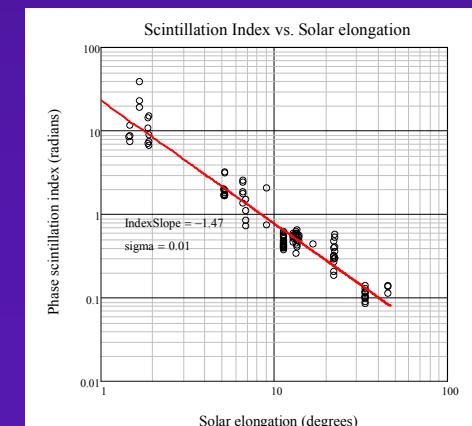
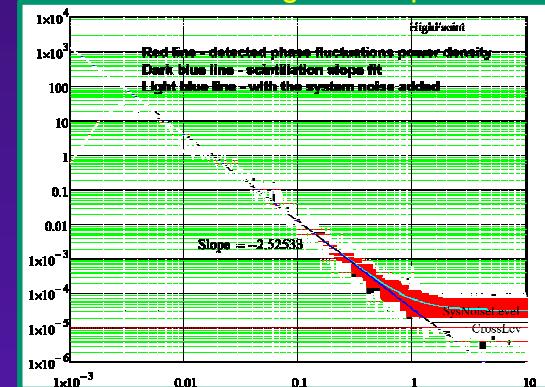


20m Wettzell telescope

Post-Phase Lock Loop  
Residual phase of the carrier line

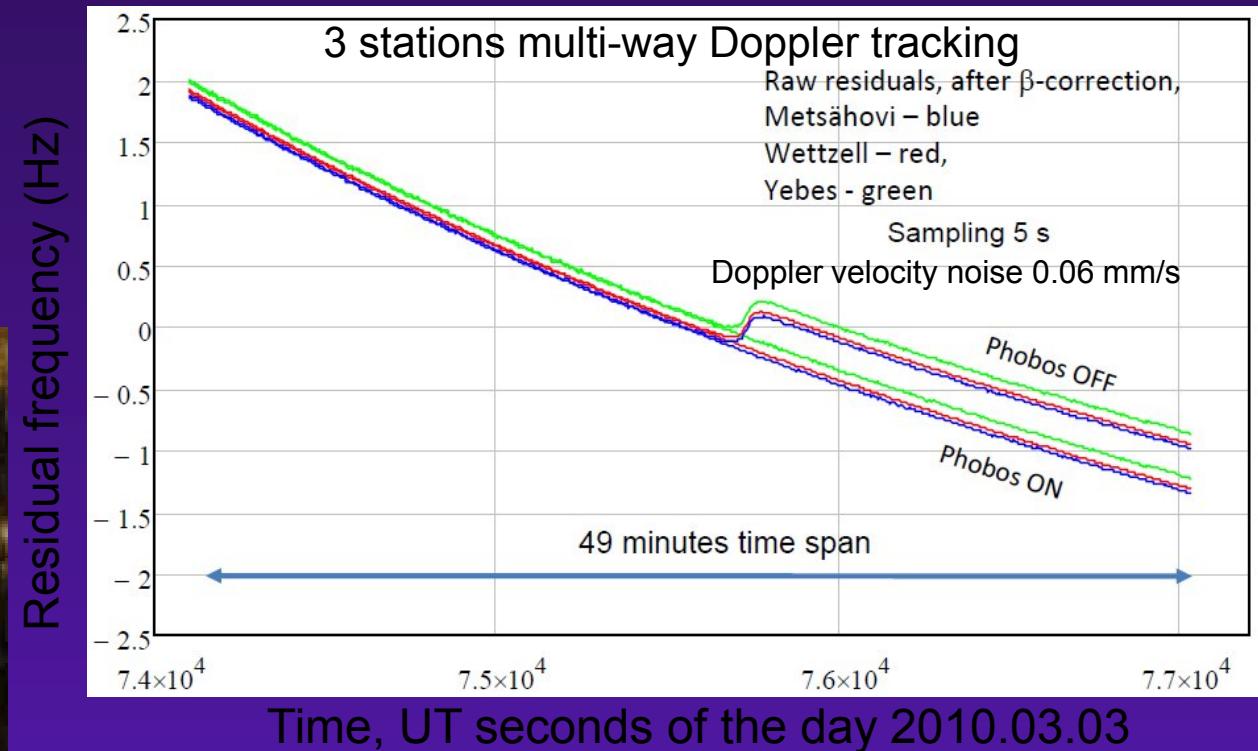
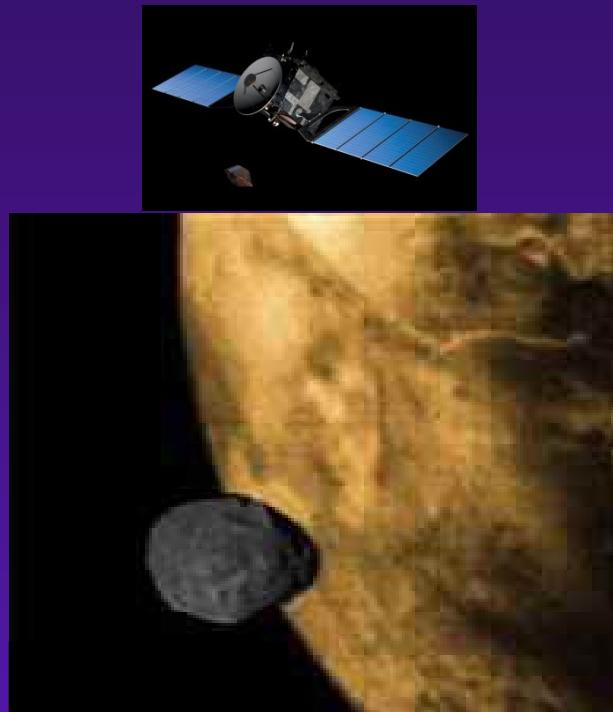


Spectrum of phase scintillations –  
Near-Kolmogorov slope



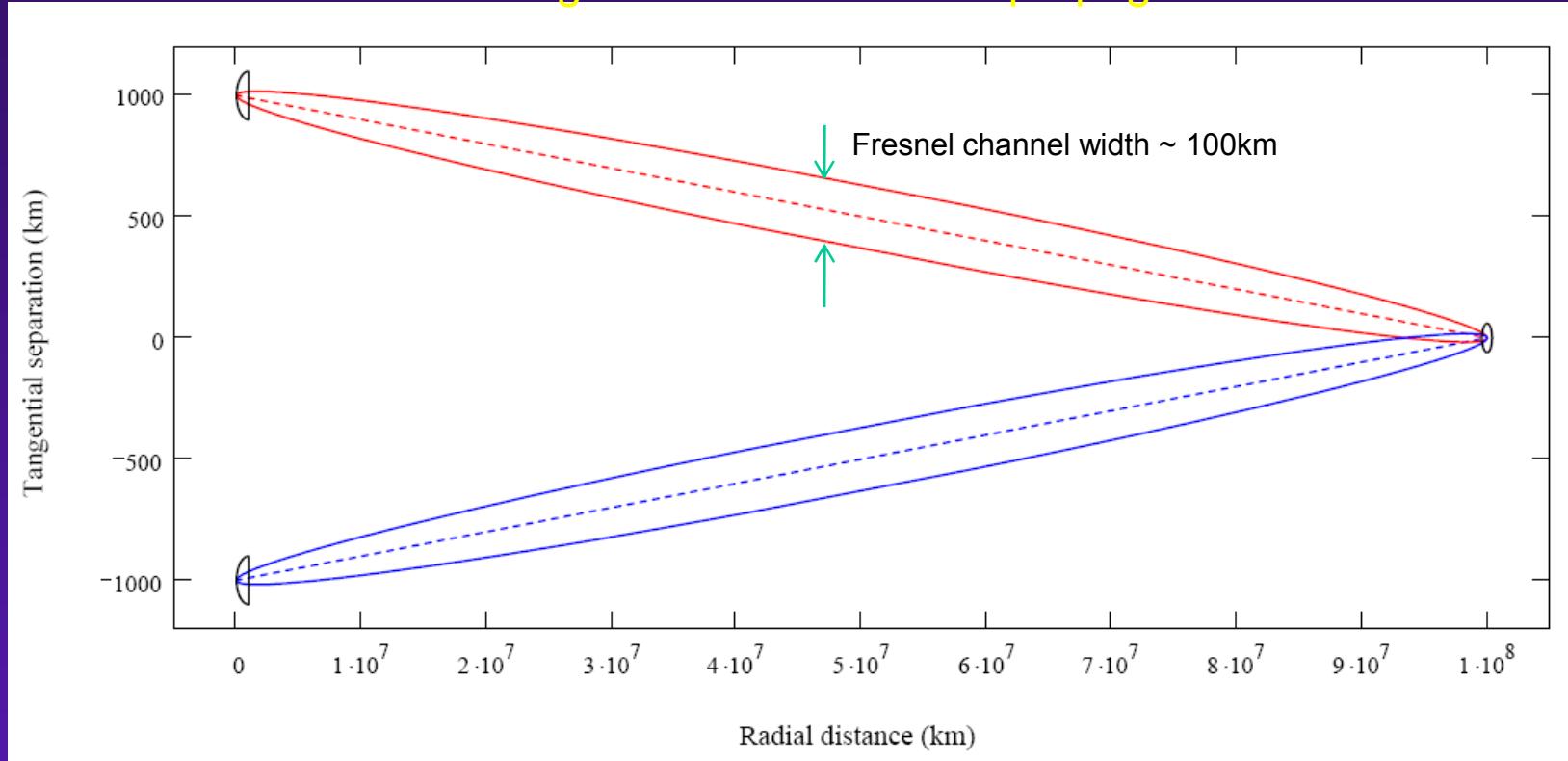
Scintillation data depending on the Solar elongation were collected using several EVN antennas: Metsähovi (Fl), Medicina, Matera, Noto (IT), Wettzell (DE), Yebes(ES) and Pustchino (RU).

## MEX Doppler multi-way tracking demo, 2010, during Phobos fly-by



## Multi-way Doppler tracking

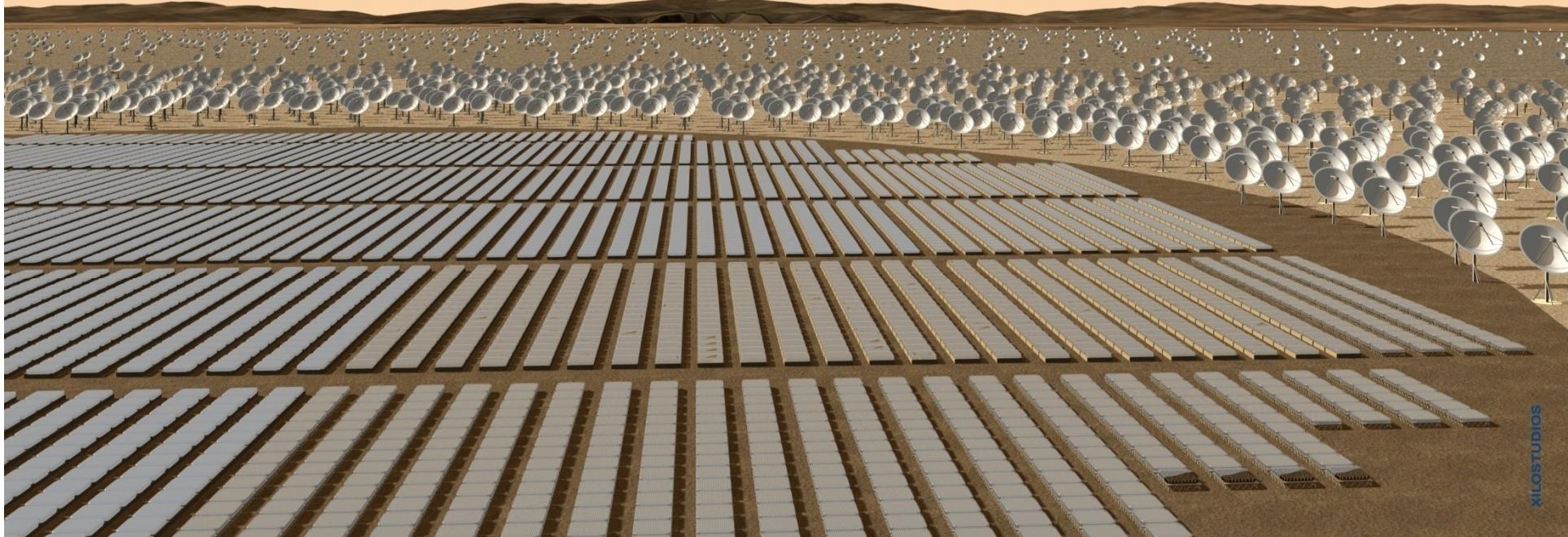
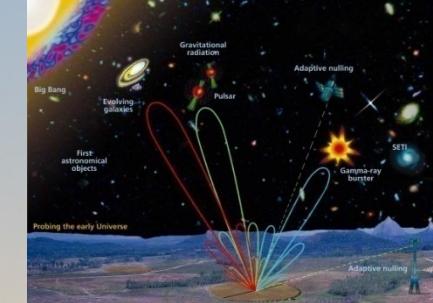
Has an advantage to discriminate the propagation effects



## 4. Direct-to Earth telemetry data reception from planetary probes, landers, penetrators, etc

# ***SKA as a PRIDE and DtE facility***

- Sensitivity gain over a large DSN-style antenna >100
- Operational life of pathfinders (e.g. AAVP) coincides with e.g. Phobos-Grunt (2012+) and ExoMars (2016+)
- Operational life coincides with major next Outer Planet missions (2022+)
- Data rate of DtE Huygens-style (~10 W) probe signal on Earth with SKA is possible at 30–100 bps





# Direct to Earth (backup) data transfer option



Estimation of the data transfer rate  
from EVE probes (balloon and lander) directly to Earth

Assuming an isotropic Tx power 5 W@0dBi, frequency ~400 MHz, distance 0.7 AU

Shannon limit data rate  $D_r = \Delta F * \log_2(1 + SNR_{1Hz}/\Delta F)$  for  $SNR_{1Hz}/\Delta F = 4$

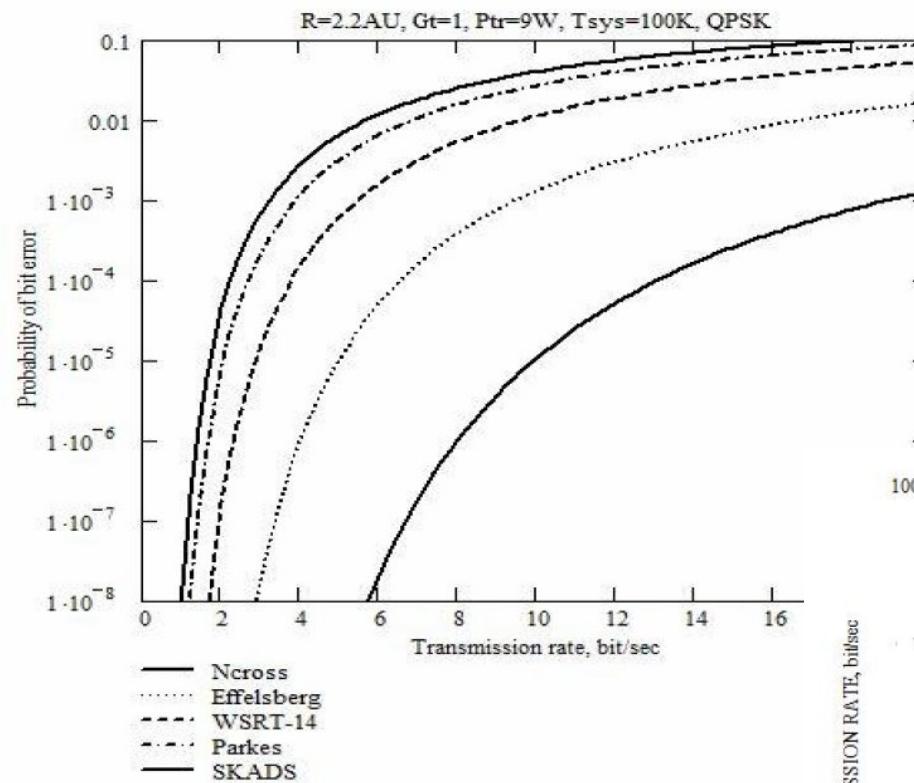
Several large-aperture radio telescopes with UHF frequency coverage are considered

Radio telescopes and their parameters:

	Westerbork	Effelsberg	Green Bank	Medicina	Arecibo	SKA=30%
Aperture	14 x 25m	100 m	100 m	30,000 m <sup>2</sup>	300 m	300,000 m <sup>2</sup>
Frequency range (MHz)	300-450	350-450	300-500	407-409	425-435	300-500
Aperture efficiency	0.35	0.6	0.6	0.4	0.4	0.4
Tsys (K)	200	120	50	150	80	100
SNR( in 1Hz)	35	110	270	230	1100	3500
Shannon Limit (bps)	20	60	150	130	600	2000
BPSK @BER<10 <sup>-3</sup> (bps)	5	12	30	25	120	400
TRL (as per 2007)	8	7	8	8	8	3

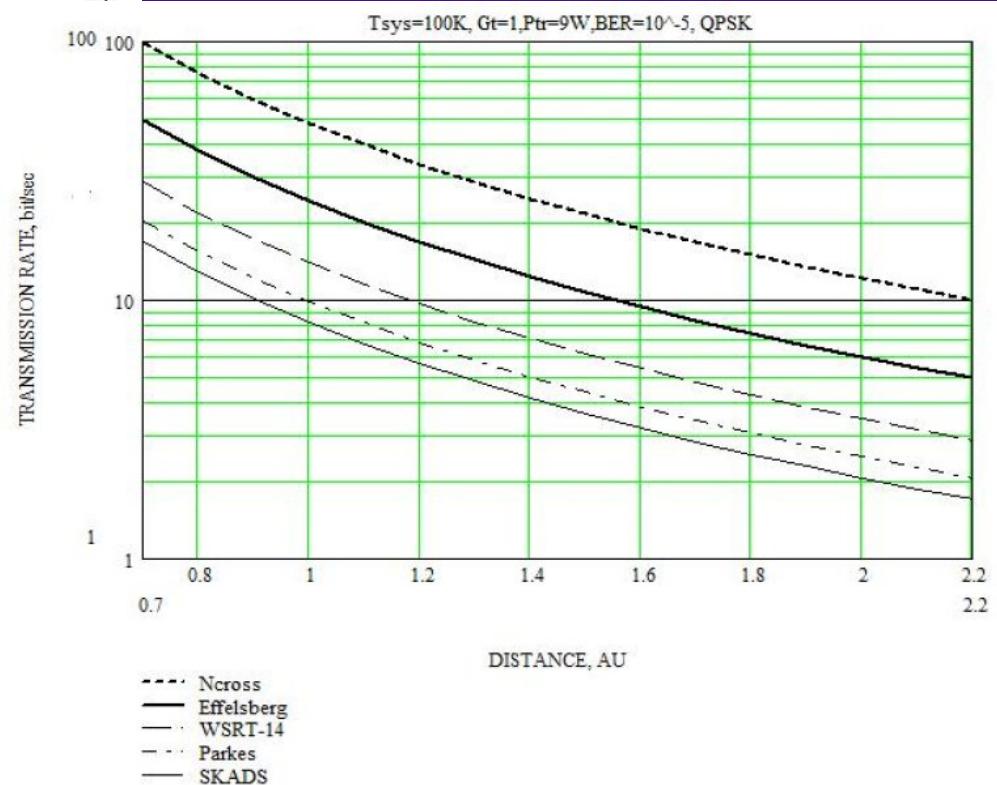


# *Closer to Earth: the DtE case for ExoMars*



## ExoMars parameters

Transmitter power:	12 W
Unmodulated carrier:	25%
Antenna gain:	1
Band:	400 MHz
Distance:	0.7 – 2.2 AU



SKA pathfinder technology at work:

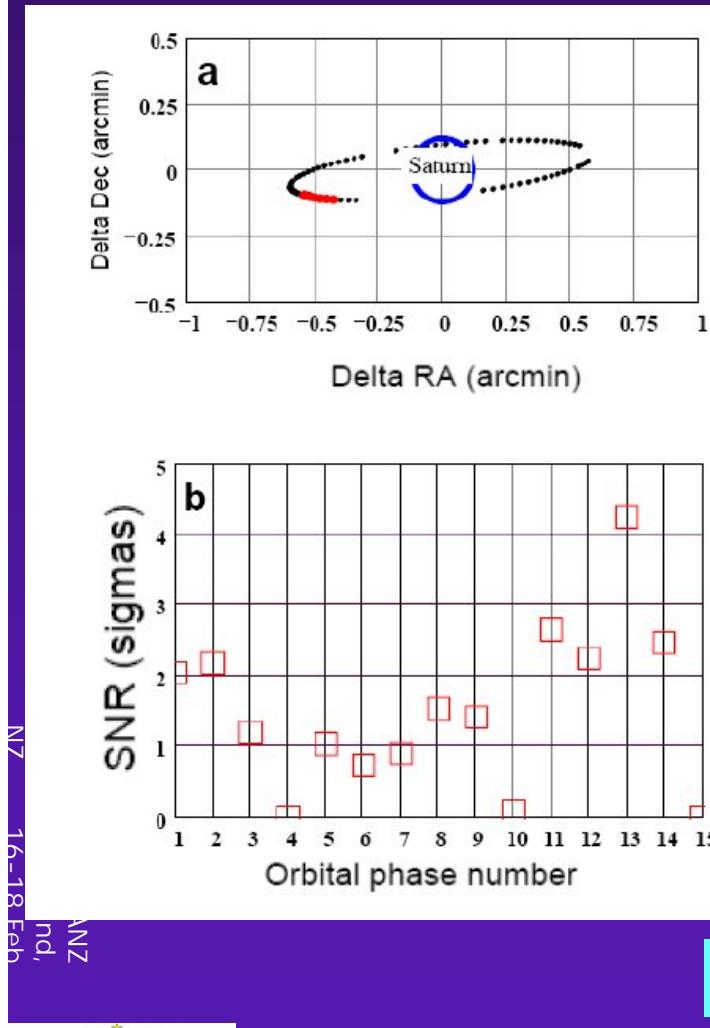
NCross+BEST  
EMBRACE (4 tiles)  
Tsys = 100 K

Fridman et al. 2009, in prep

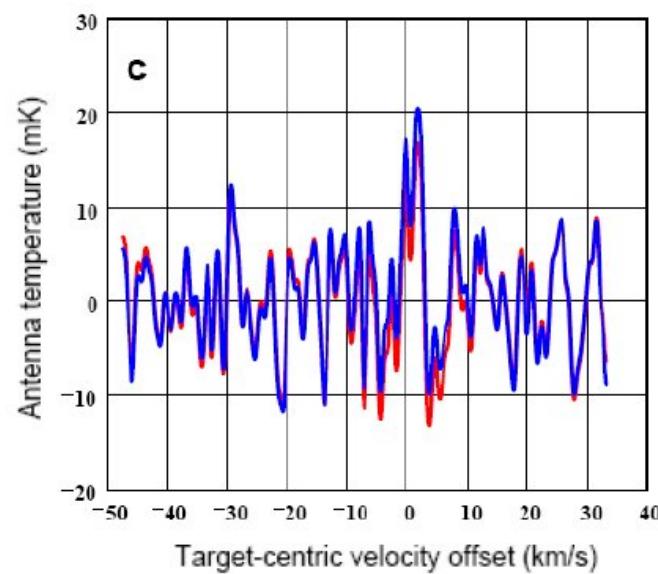
## 5. Passive radio spectroscopy of the natural molecular lines from planetary environments

# *Expect unexpected spin-offs...*

**Water maser detection in Enceladus – as a Huygens VLBI tracking spin-off  
(spectral line single dish experiment in VLBI continuum mode...)**



~350 “in gap” hrs at Medicina and Metsähovi;  
in collaboration with INAF, HUT, U Kentucky



- *Puzzling physics*
- *Ongoing study*

*Pogrebenko et al. 2009, IAU Symp 263 (Rio), in press*

# Water masers in Kronian system

Detection reported season (2006-2008)...

...Un-detection reported (season 2009)

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## LETTER TO THE EDITOR

### Water masers in the Saturnian system

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## ABSTRACT

**Context.** The presence of water has long been seen as a key condition for life in planetary environments. The Cassini spacecraft discovered water vapour in the Saturnian system by detecting absorption of UV emission from a background star. Investigating other possible manifestations of water is essential, one of which, provided physical conditions are suitable, is maser emission.

**Aims.** We report detection of water maser emission at 22 GHz associated with several Kronian satellites using Earth-based radio telescopes.

**Methods.** We searched for water maser emission in the Saturnian system in an observing campaign using the M€€s€hovi and Medicina radio telescopes. Spectral data were Doppler-corrected over orbital phase for the Saturnian satellites, yielding detections of water maser emission associated with the moons Hyperion, Titan, Enceladus, and Atlas.

**Results.** The detection of Saturnian water molecules by remote astronomical observation can be combined with in situ spacecraft measurements to harmonise the physical model of the Saturnian system.

## A Search for Water Masers in the Saturnian System

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## Abstract

We searched for H<sub>2</sub>O 6(1,6)-5(2,3) maser emission at 22.235 GHz from several Saturnian satellites with the Nobeyama 45m radio telescope in May 2009. Observations were made for Titan, Hyperion, Enceladus and Atlas, for which Pogrebko *et al.* (2009) had reported detections of water masers at 22.235 GHz, and in addition for Iapetus and other inner satellites. We detected no emission of the water maser line for all the satellites observed, although sensitivities of our observations were comparable or even better than those of Pogrebko *et al.* We infer that the water maser emission from the Saturnian system is extremely weak, or sporadic in nature. Monitoring over a long period and obtaining statistical results must be made for the further understanding of the water maser emission in the Saturnian system.

**Key words:** planets and satellites: individual Titan, Hyperion, Iapetus, Enceladus and Atlas

Prompting for more observations and analysis

Currently developing new radio astronomy instruments like e-EVN, LOFAR , ALMA and SKA will broaden the horizons of the Earth-based research of the mysteries of the Solar System

Meanwhile, use of the existing instruments will help to set up the upcoming experiments for a better return.

Thanks !

Questions?